US009140894B2

(12) **United States Patent**
Kim et al.

(10) **Patent No.: US 9,140,894 B2**
(45) **Date of Patent: Sep. 22, 2015**

(54) **ELECTRO-WETTING DISPLAY APPARATUS**

(71) Applicant: **Amazon Technologies, Inc.**, Seattle, WA (US)

(72) Inventors: **Myung-Eun Kim**, Hwaseong-si (KR); **Sang-Il Kim**, Yongin-si (KR); **Yeuntae Kim**, Suwon-si (KR); **Yujin Kim**, Yongin-si (KR); **Byungseok Choi**, Seoul (KR)

(73) Assignee: **Amazon Technologies, Inc.**, Reno, NV (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/609,198**

(22) Filed: **Jan. 29, 2015**

(65) **Prior Publication Data**

US 2015/0146274 A1 May 28, 2015

Related U.S. Application Data

(63) Continuation of application No. 13/547,384, filed on Jul. 12, 2012, now Pat. No. 8,964,276.

(30) **Foreign Application Priority Data**

Feb. 13, 2012 (KR) 10-2012-0014429

(51) **Int. Cl.**
G02B 26/02 (2006.01)
G02B 26/00 (2006.01)

(52) **U.S. Cl.**
CPC ***G02B 26/005*** (2013.01); ***G02B 26/02*** (2013.01)

(58) **Field of Classification Search**
CPC G02B 26/00; G02B 26/004; G02B 26/005
USPC 359/228, 290, 291
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2010/0090930 A1* 4/2010 Marcu et al. 345/72
2012/0098812 A1 4/2012 Bae et al.

FOREIGN PATENT DOCUMENTS

JP 2006098679 A 4/2006
JP 2010211037 A 9/2010
KR 1020070081736 6/2007
KR 1020080071250 A 8/2008

OTHER PUBLICATIONS

Office action for U.S. Appl. No. 13/547,384, mailed on Jul. 7, 2014, Kim et al., "Electro-Wetting Display Apparatus", 6 pages.

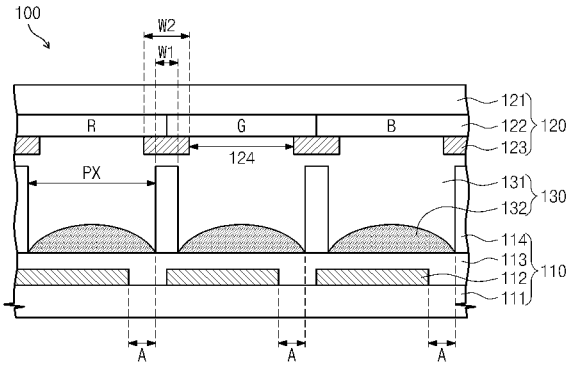
* cited by examiner

Primary Examiner — Euncha Cherry
(74) *Attorney, Agent, or Firm* — Lee & Hayes, PLLC

(57) **ABSTRACT**

An electro-wetting display apparatus includes a first base substrate, a plurality of first electrodes on the first base substrate, an insulating layer which overlaps the first electrodes, a pixel wall on the insulating layer, where the pixel wall partitions a plurality of pixels respectively corresponding to the plurality of first electrodes, a second base substrate which face the first base substrate, a second electrode on the second base substrate and including a plurality of openings, and a fluid between the first base substrate and the second base substrate and in the plurality of pixels. The movement of the fluid in the plurality of pixels is controlled by voltages respectively applied to the first electrodes and the second electrode.

24 Claims, 12 Drawing Sheets



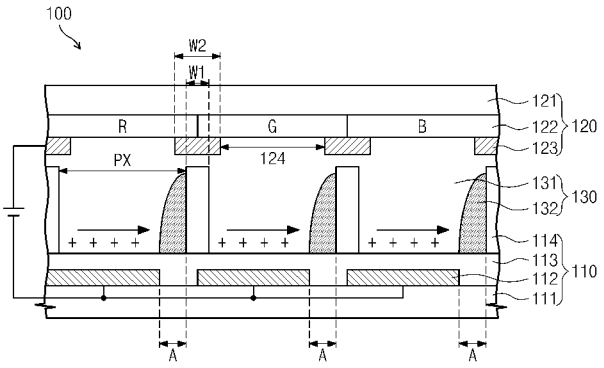


Fig. 1

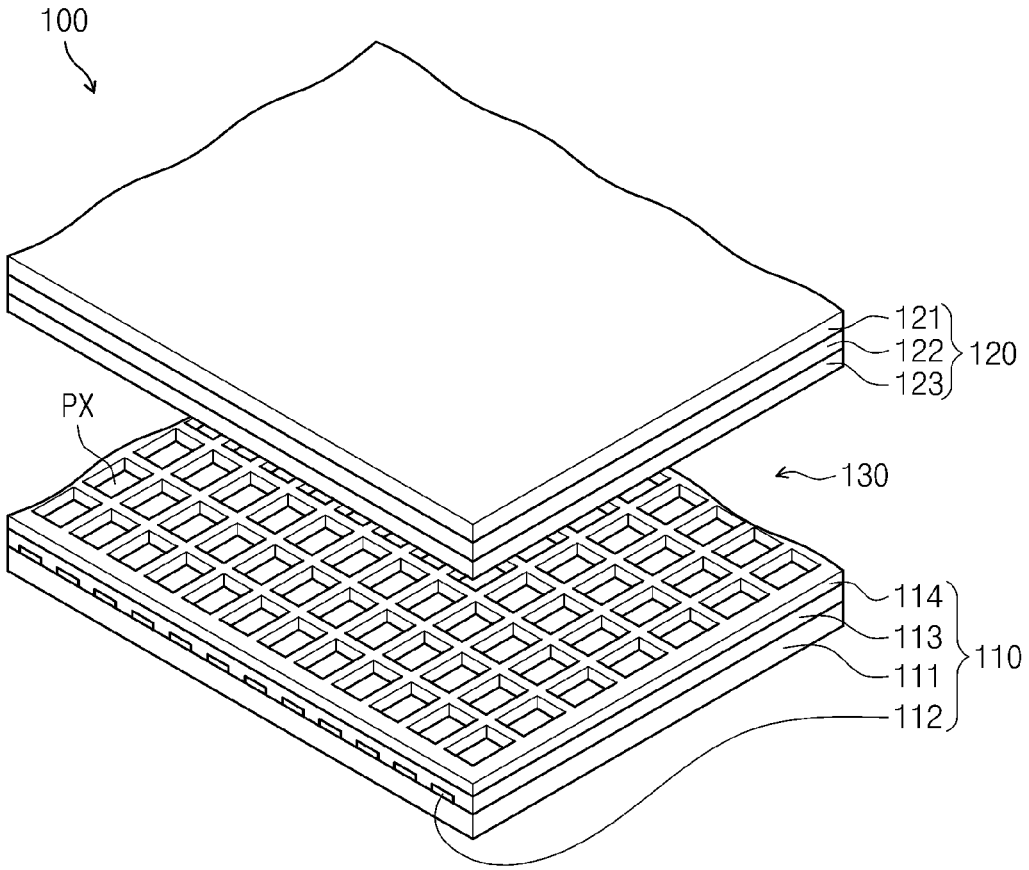


Fig. 2

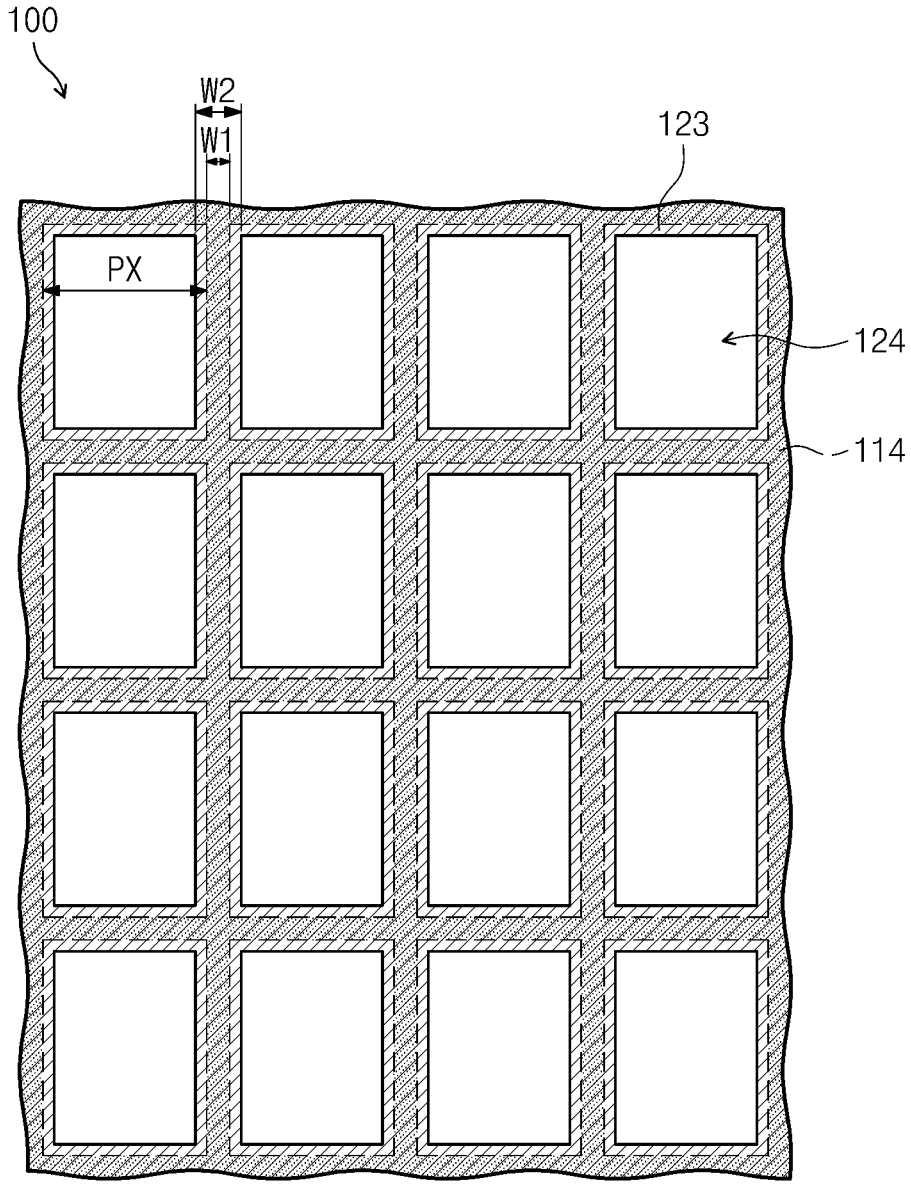


Fig. 3A

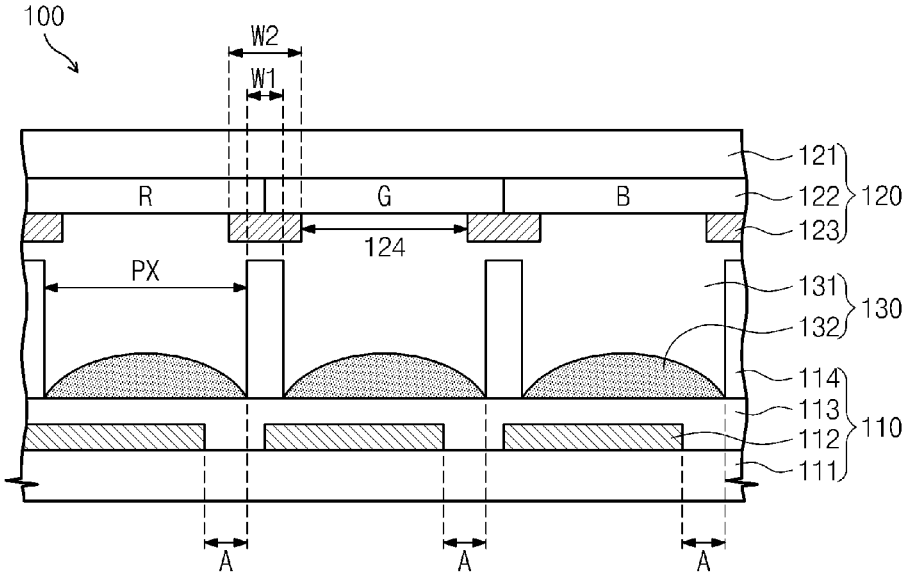

100
W2
W1
121
R
G
B
122
120
123
124
PX
131
130
132
114
113
110
112
111
A
A
A

Fig. 3B

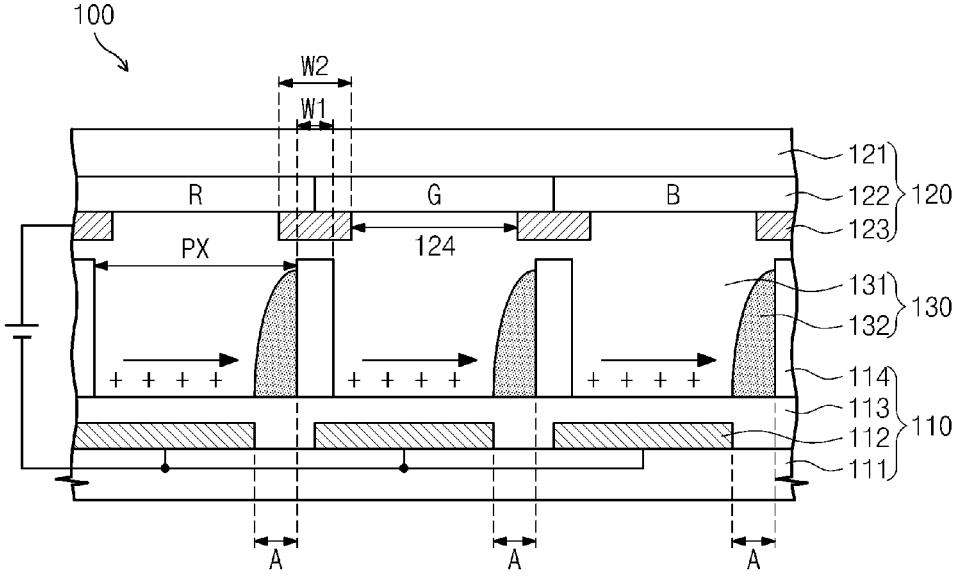

100
W2
W1
121
R
G
B
122
120
123
124
PX
131
130
132
+ + + +
+ + + +
+ + + +
114
113
110
112
111
A
A
A

Fig. 4

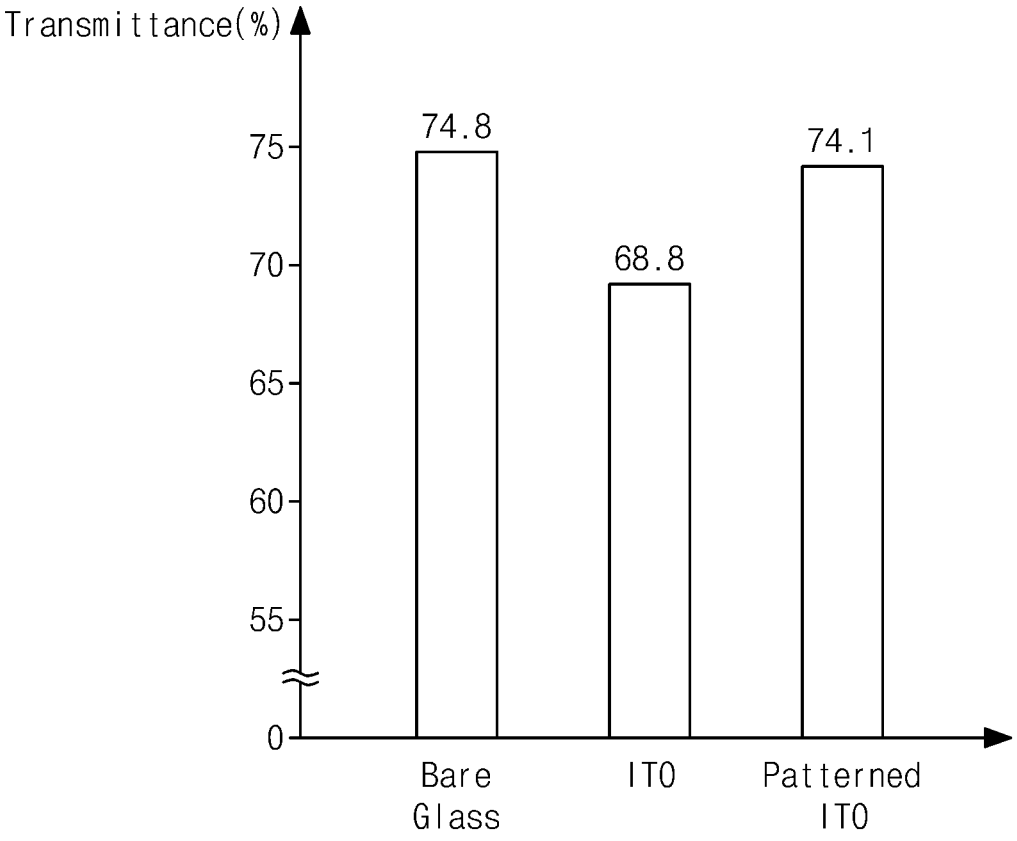

Transmittance(%)
75
70
65
60
55
0
74.8
68.8
74.1
Bare Glass
ITO
Patterned ITO

Fig. 5

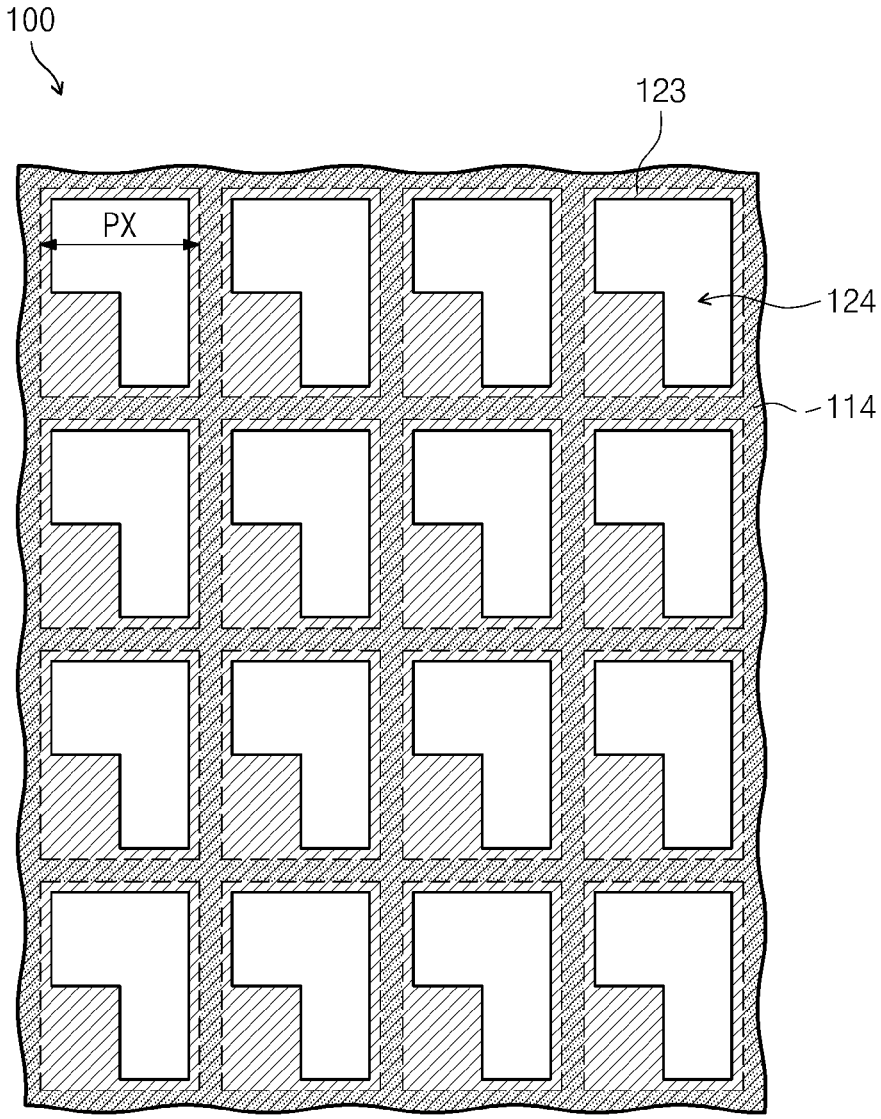


Fig. 6

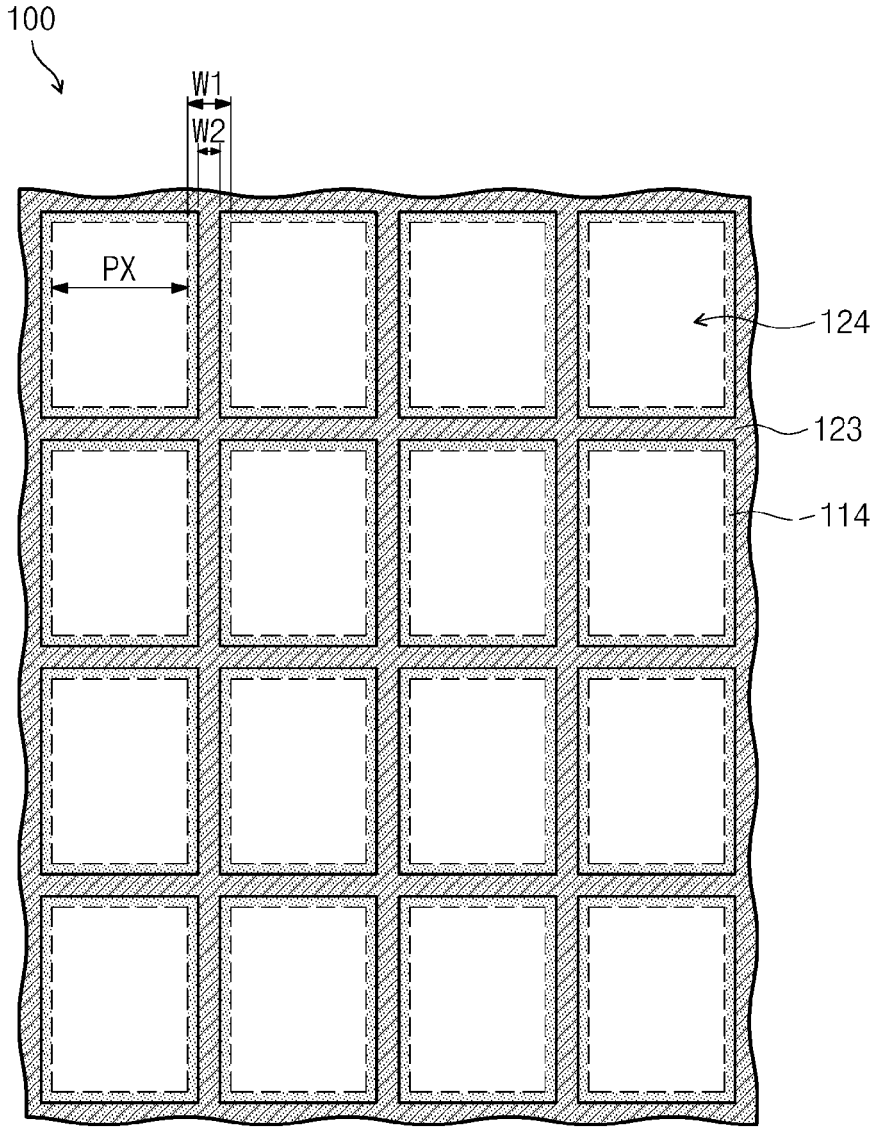


Fig. 7A

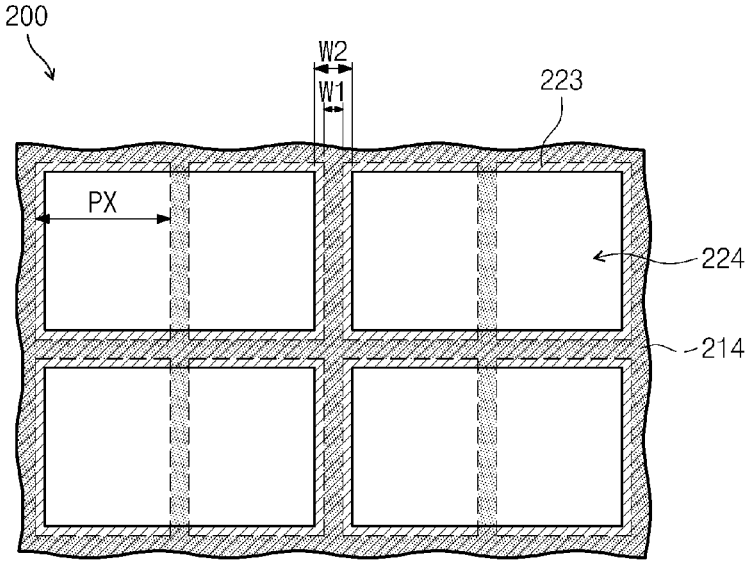


Fig. 7B

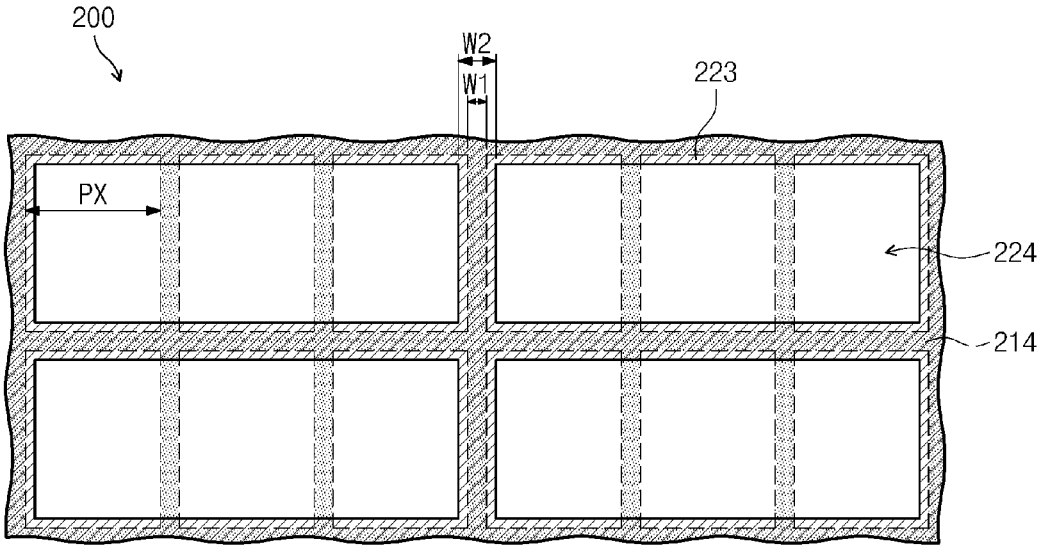


Fig. 7C

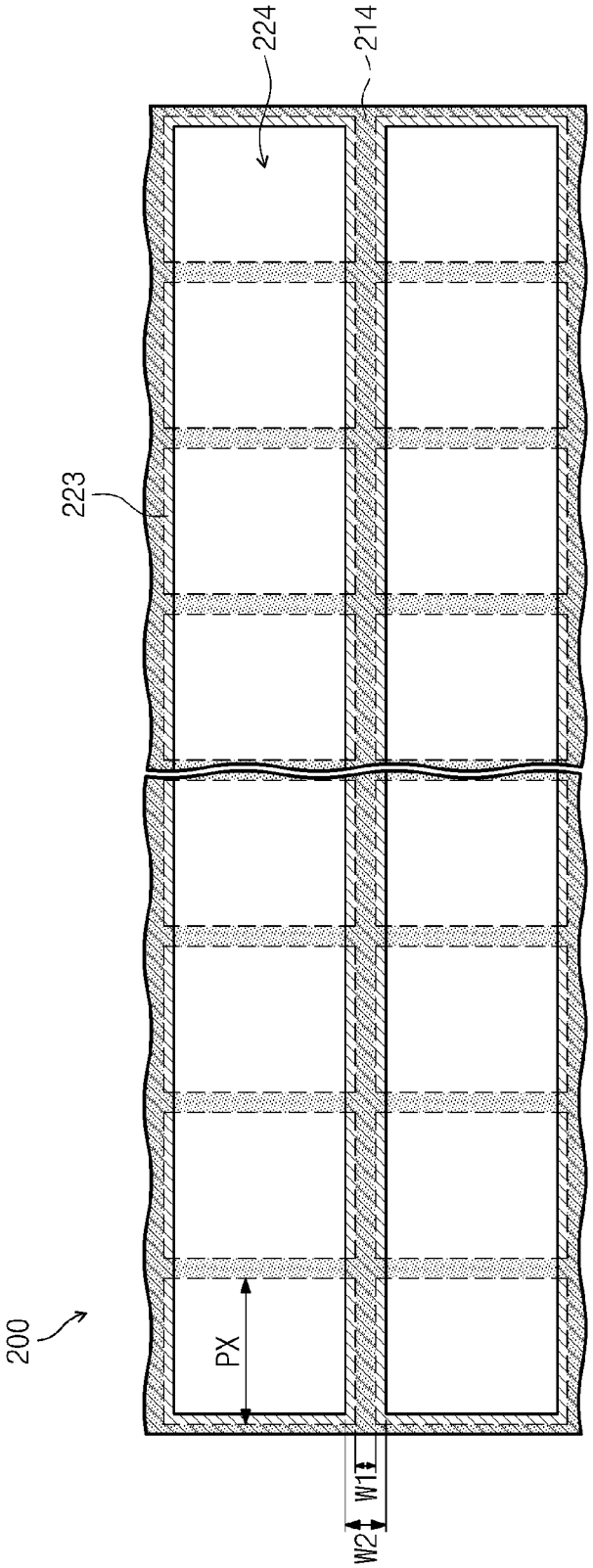


Fig. 8A

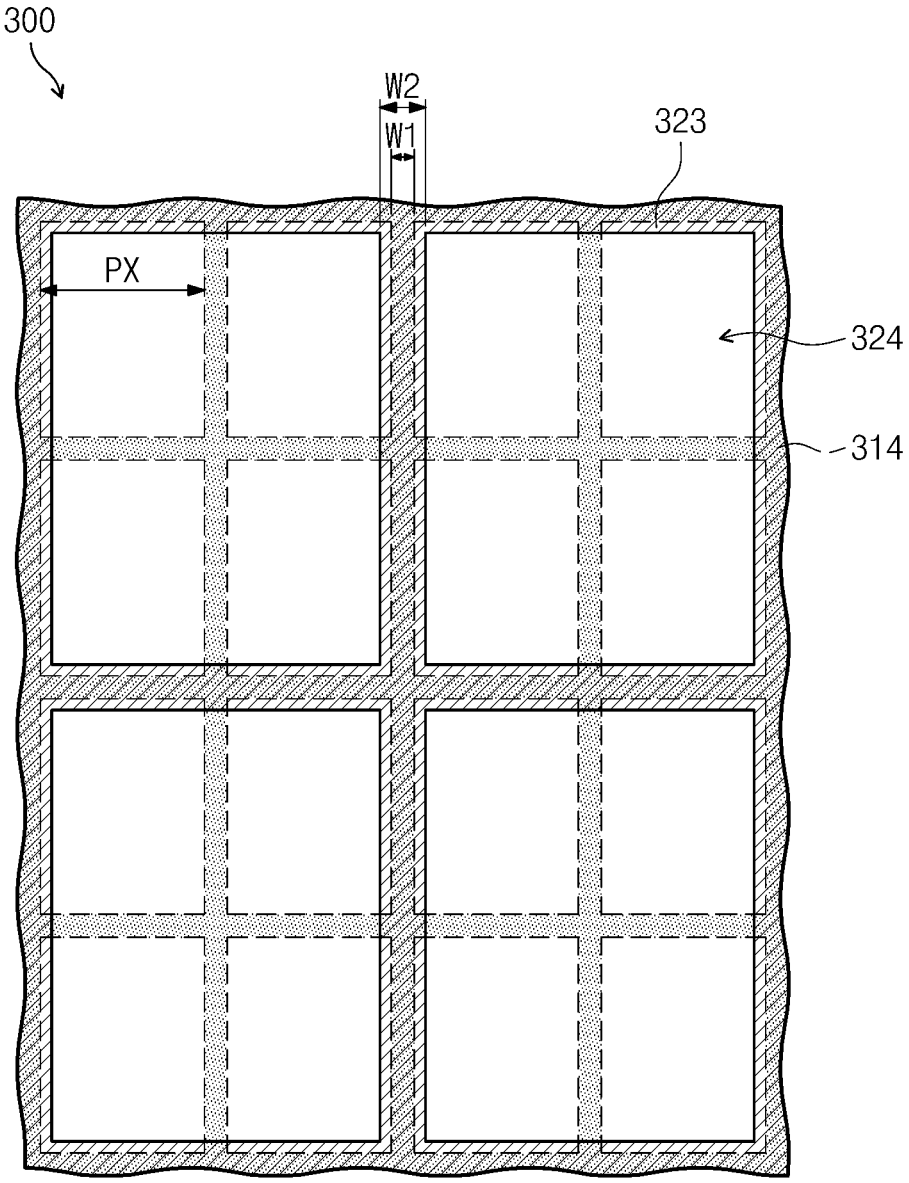


Fig. 8B

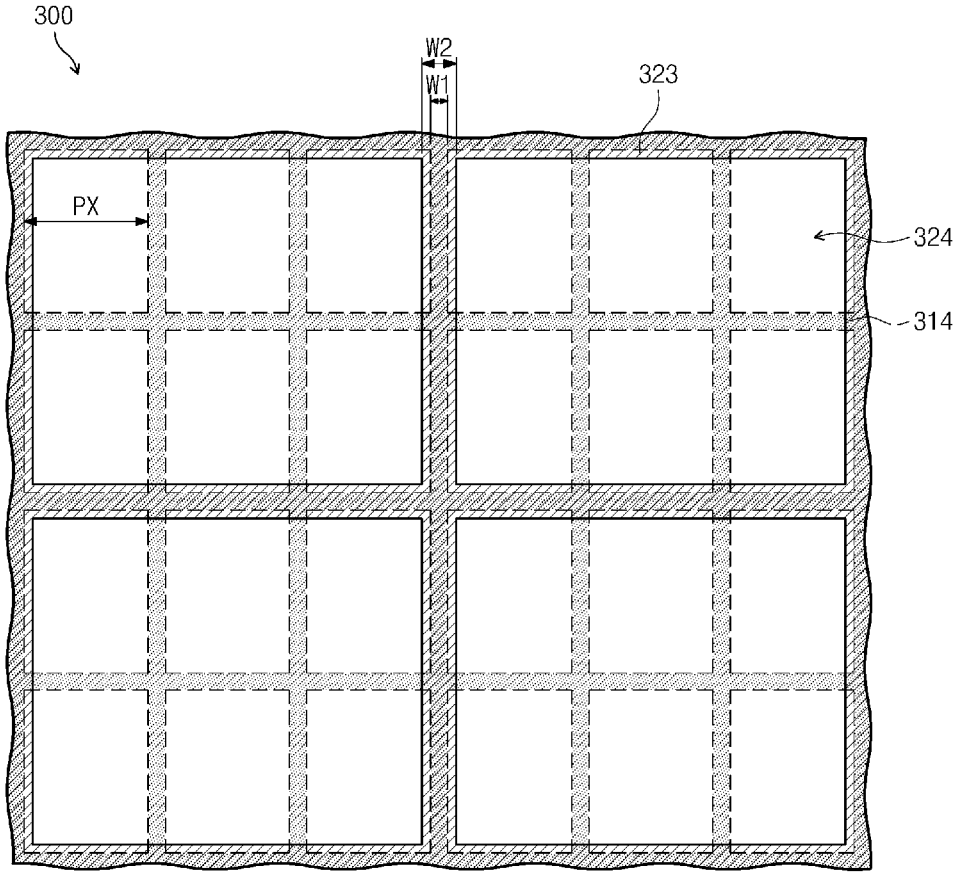


Fig. 8C

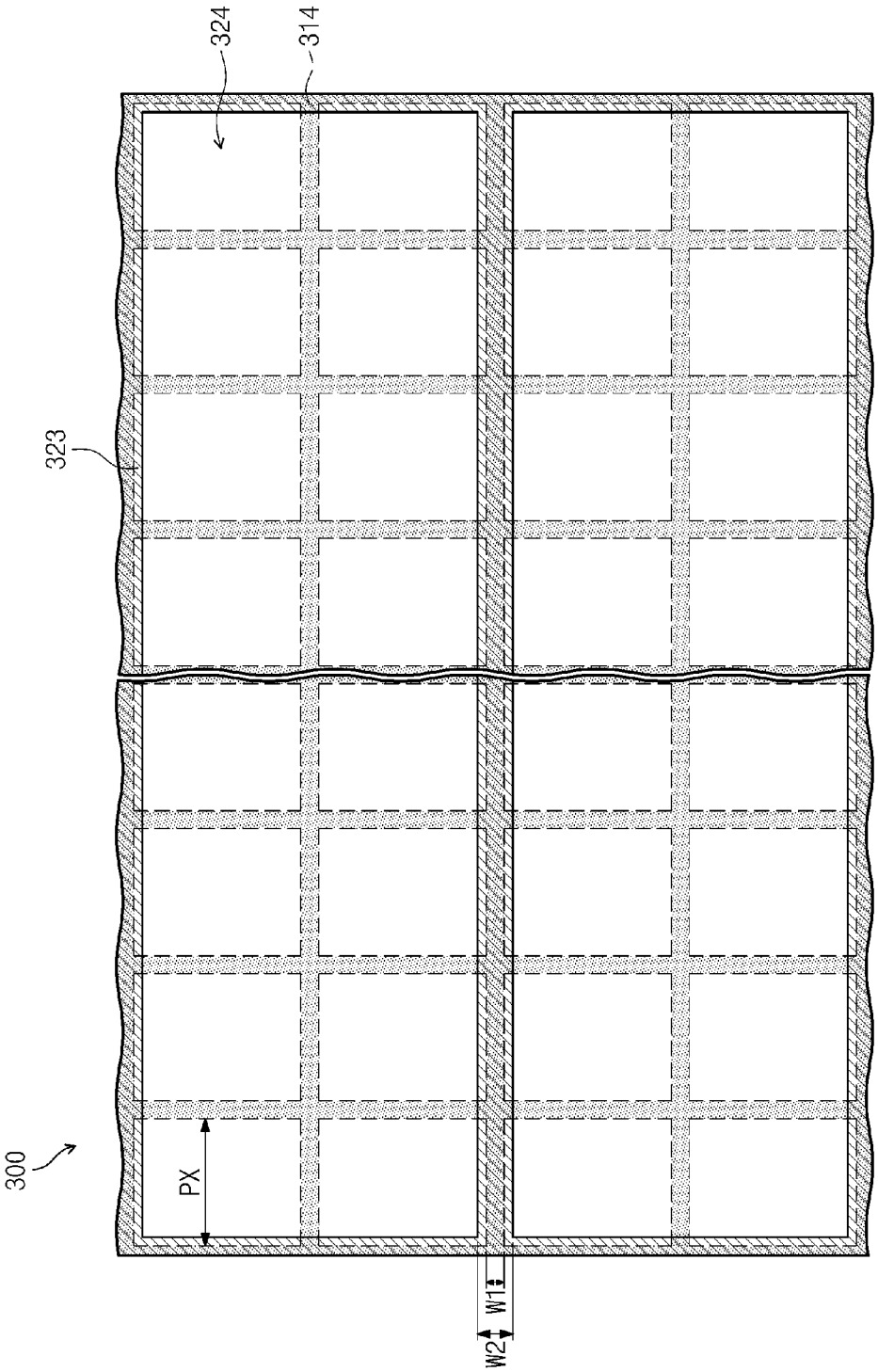
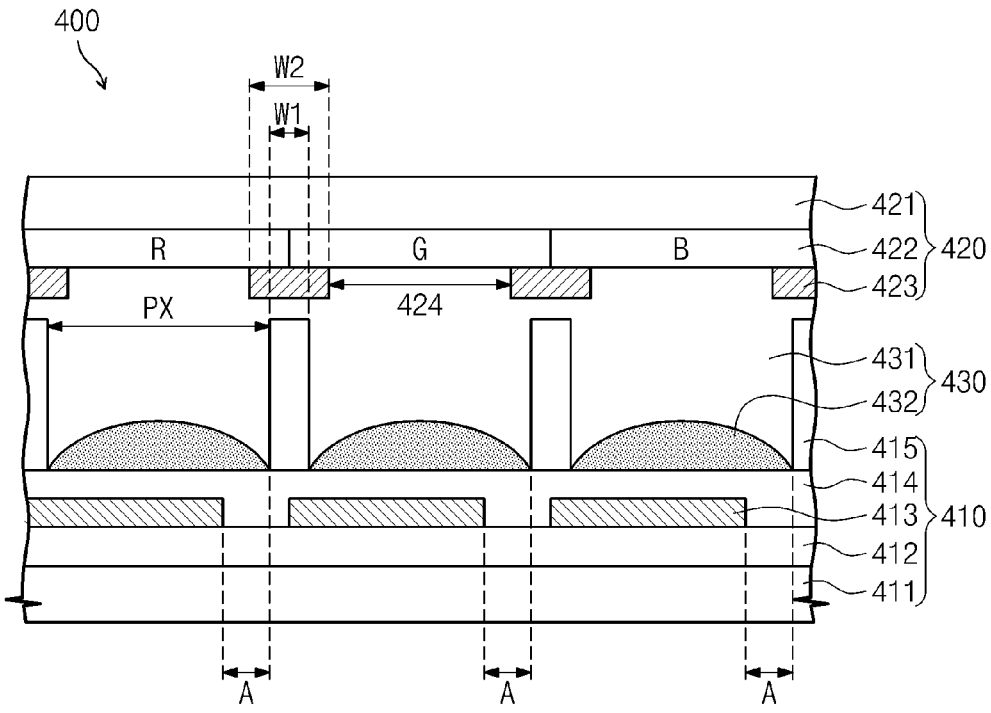


Fig. 9


400
W2
W1
421
R
G
B
422
420
423
424
PX
431
430
432
415
414
413
410
412
411
A
A
A

ELECTRO-WETTING DISPLAY APPARATUS

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of and claims priority to U.S. patent application Ser. No. 13/547,384, filed Jul. 12, 2012, which claims priority to Korean Patent Application No. 10-2012-0014429, filed Feb. 13, 2012, and all the benefits accruing under 35 U.S.C. §119, which are incorporated herein by reference.

BACKGROUND

1. Field

The disclosure relates to an electro-wetting display apparatus. More particularly, the disclosure relates to an electro-wetting display apparatus capable of improving reflectance and transmittance thereof.

2. Description of the Related Art

An electro-wetting display apparatus, which has properties of low power consumption, high visibility, etc. when compared with a liquid crystal display, has been spotlighted. The electro-wetting display apparatus utilizes a principle in which two fluids, such as water and oil, are not mixed with each other.

The electro-wetting display apparatus is classified into a transmissive-type and a reflective-type. The transmissive-type electro-wetting display apparatus includes an upper substrate including an upper transparent electrode formed thereon, a lower substrate facing the upper substrate and including a plurality of lower transparent electrodes formed thereon, and a fluid disposed between the upper substrate and the lower substrate. The fluid includes a polar fluid and a non-polar fluid.

The reflective-type electro-wetting display apparatus further includes a reflective layer to reflect light. Movements of the polar fluid and the non-polar fluid are controlled according to a power source voltage applied to the upper transparent electrode and the lower transparent electrode, thereby displaying gray scales.

When the electro-wetting display apparatus is operated in a transmissive mode, the light passing through the upper substrate transmits through the lower substrate. In the reflective-type electro-wetting display apparatus, the light passing through the upper substrate is reflected by the reflective layer and the reflected light transmits again through the upper substrate. Accordingly, the light passes through the upper transparent electrode of the upper substrate one time in the transmissive-type electro-wetting display apparatus and passes through the upper transparent electrode of the upper substrate two times in the reflective-type electro-wetting display apparatus.

Recently, a technology is required to improve reflectance and transmittance of the electro-wetting display apparatus.

SUMMARY

The disclosure provides an electro-wetting display apparatus improving a transmittance and reflectance thereof.

Embodiments provide an electro-wetting display apparatus including a first base substrate, a plurality of first electrodes on the first base substrate, an insulating layer which overlaps the plurality of first electrodes, a pixel wall on the insulating layer, where the pixel wall partitions a plurality of pixels respectively corresponding to the plurality of first electrodes, a second base substrate which faces the first base substrate, a second electrode on the second base substrate and including a plurality of openings, and a fluid between the first base substrate and the second base substrate and respectively in the plurality of pixels. The movement of the fluid in the plurality of pixels is controlled by voltages respectively applied to the first electrodes and second electrode.

The plurality of openings may respectively correspond to the plurality of pixels.

Each of the plurality of openings may have a rectangular shape, and a width of the pixel wall between two adjacent pixels may be smaller than a width between two adjacent openings.

Each of the plurality of openings may have a rectangular shape, and a width of the pixel wall between two adjacent pixels may be larger than a width between two adjacent openings.

Each of the plurality of openings may have a rectangular shape, and a width of the pixel wall between two adjacent pixels may be equal to a width between two adjacent openings.

The plurality of pixels may be arranged in "n" rows by "m" columns and the plurality of openings may respectively correspond to a plurality of pixel units. Each of the plurality of pixel units includes two or more pixels, but equal to or less than "m" pixels, in each row.

The plurality of pixels may be arranged in "n" rows by "m" columns and the plurality of openings may respectively correspond to a plurality of pixel units. Each of the plurality of pixel units includes two pixels in column, and two or more pixels but less than "m" pixels in each row.

According to the above, one or more embodiments of the electro-wetting display apparatus includes an upper transparent electrode including openings, so the electro-wetting display apparatus may improve the transmittance and reflectance thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other advantages of the invention will become readily apparent by reference to the following detailed description when considered in conjunction with the accompanying drawings wherein:

FIG. **1** is an exploded perspective view showing an exemplary embodiment of an electro-wetting display apparatus according to the invention;

FIG. **2** is a plan view showing an exemplary embodiment of a plan structure of an electro-wetting display apparatus according to the invention;

FIGS. **3**A and **3**B are cross-sectional view showing an exemplary embodiment of a cross-sectional structure of an electro-wetting display apparatus according to the invention;

FIG. **4** is a graph showing experimental results of a variety of electro-wetting display apparatus structures according to the invention;

FIG. **5** is a plan view showing another exemplary embodiment of a second electrode of an electro-wetting display apparatus according to the invention;

FIG. **6** is a plan view showing another exemplary embodiment of a second electrode of an electro-wetting display apparatus according to the invention;

FIGS. **7**A to **7**C are plan views showing other exemplary embodiments of plan structures of an electro-wetting display apparatus according to the invention;

FIGS. **8**A to **8**C are plan views showing still other exemplary embodiments of plan structures of an electro-wetting display apparatus according to the invention; and

FIG. **9** is a cross-sectional view showing another exemplary embodiment of a cross-sectional structure of an electro-wetting display apparatus according to the invention.

DETAILED DESCRIPTION

It will be understood that when an element or layer is referred to as being "on" another element or layer, the element or layer can be directly on another element or layer or intervening elements or layers. In contrast, when an element is referred to as being "directly on" another element or layer, there are no intervening elements or layers present. Like numbers refer to like elements throughout. As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

It will be understood that, although the terms first, second, third, etc., may be used herein to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers and/or sections should not be limited by these terms. These terms are only used to distinguish one element, component, region, layer or section from another region, layer or section. Thus, a first element, component, region, layer or section discussed below could be termed a second element, component, region, layer or section without departing from the teachings of the invention.

Spatially relative terms, such as "lower," "under," "above," "upper" and the like, may be used herein for ease of description to describe the relationship of one element or feature to another element(s) or feature(s) as illustrated in the figures. It will be understood that the spatially relative terms are intended to encompass different orientations of the device in use or operation, in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as "lower" or "under" relative to other elements or features would then be oriented "above" relative to the other elements or features. Thus, the exemplary term "under" can encompass both an orientation of above and below. The device may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein interpreted accordingly.

The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used herein, the singular forms "a," "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises," "comprising," "includes" and/or "including," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

Embodiments of the invention are described herein with reference to cross-section illustrations that are schematic illustrations of idealized embodiments (and intermediate structures) of the invention. As such, variations from the shapes of the illustrations as a result, for example, of manufacturing techniques and/or tolerances, are to be expected. Thus, embodiments of the invention should not be construed as limited to the particular shapes of regions illustrated herein but are to include deviations in shapes that result, for example, from manufacturing.

Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

Hereinafter, the invention will be explained in detail with reference to the accompanying drawings.

FIG. **1** is an exploded perspective view showing an exemplary embodiment of an electro-wetting display apparatus according to the invention and FIG. **2** is a plan view showing an exemplary embodiment of a plan structure of an electro-wetting display apparatus according to the invention. For the convenience of explanation, a pixel wall has been shown as a dotted line and a darker gray color, and a second electrode has been shown as a solid line and an area shaded with an oblique line in FIG. **2**.

Referring to FIGS. **1** and **2**, the electro-wetting display apparatus **100** includes a first substrate **110**, a second substrate **120** facing the first substrate **110**, and a fluid **130** disposed between the first substrate **110** and the second substrate **120**.

The first substrate **110** includes a first base substrate **111**, a plurality of first electrodes **112** disposed on the first base substrate **111**, an insulating layer **113** disposed on the first base substrate **111** to cover the first electrodes **112**, and a pixel wall **114** disposed on the insulating layer **113** to define areas for pixels PX. The first electrodes **112** respectively correspond to the pixels PX.

The second substrate **120** includes a second base substrate **121** facing the first base substrate **111**, color filters **122** disposed on the second base substrate **121**, and a second electrode **123** disposed on the color filters **122**. The second electrode **123** includes a plurality of openings **124** extended through a thickness of the second electrode **123**. The color filters **122** may include color pixels to display one of red, green and blue colors.

The openings **124** of the second electrode **123** respectively correspond to the pixels PX defined on the first substrate **110**. The openings **124** are areas excluding material of the second electrode **123** and are enclosed openings solely defined by the second electrode **123**.

The pixels PX are arranged in "n" rows by "m" columns, where "n" and "m" are constant numbers larger than zero (0). The pixels PX may include a red pixel R, a green pixel G, and a blue pixel B respectively corresponding to the color filters **122**. In addition, in the pixels PX, the red, green and blue pixels are alternately and repeatedly arranged in the row and column directions. However, the arrangement of the pixels PX should not be limited thereto or thereby.

Each of the first and second base substrates **111** and **121** may be a glass substrate or a plastic substrate. When the first and second base substrates **111** and **121** are the plastic substrate, a flexible display may be embodied.

The first electrodes **112** may include a transparent conductive material, such as indium tin oxide, conductive polymer, carbon nanotube, etc. The second electrode **123** may include a transparent conductive material, such as indium tin oxide.

The openings **124** have a rectangular planar shape, but the shape should not be limited to the rectangular shape. Alternatively, for instance, each opening **124** of the second electrode **123** may have a planar shape bent at a right angle.

The second electrode **123** is partially overlapped with the pixel wall **114**. In one exemplary embodiment, for example, as shown in FIG. **2**, a width W1 of the pixel walls **114** between two pixels PX adjacent to each other is smaller than a width W2 between the edges of two openings **124** adjacent to each

other. The width W2 is effectively a width of the second electrode **123** between the two openings **124** adjacent to each other.

However, the overlap area between the second electrode **123** and the pixel wall **114** should not be limited thereto or thereby. That is, the width W1 of the pixel walls **114** between two pixels PX adjacent to each other may be larger than the width W2 between two openings **124** adjacent to each other. This will be described in detail with reference to FIG. **6**.

In addition, although not shown in figures, the width W1 of the pixel walls **114** between two pixels PX adjacent to each other may be the same as the width W2 between two openings **124** adjacent to each other.

Since the second electrode **123** includes the openings **124**, the second electrode **123** has a total planar area smaller than that when the second electrode **123** is a single, unitary, indivisible body without the openings **124**. In one exemplary embodiment, for example, when the width W1 of the pixel wall **114** is smaller than the width W2 of the second electrode **123** as shown in FIG. **2**, the area of the second electrode **123** including the openings **124** is reduced by about 87.89% when compared with the area of the second electrode **123** as the single body without the openings **124**.

In addition, although not shown in figures, in the case that the width W1 of the pixel wall **114** is equal to the width W2 of the second electrode **123**, the area of the second electrode **123** including the openings **124** is reduced by more than 87.89% when compared with the area of the second electrode **123** as the single body without the openings **124**.

The fluid **130** includes a first fluid having properties of hydrophilicity as a polar fluid and a second fluid having properties of hydrophobicity as a non-polar fluid. The first fluid transmits the light incident thereto. The second fluid includes a light-blocking material such as a black dye or a material that absorbs the light. The first fluid is disposed on the second fluid.

A surface of the insulating layer **113** is surface-treated to have the hydrophobicity property or additional hydrophobic layer (not shown) is on the insulating layer **113**. The pixel wall **114** disposed on the insulating layer **113** may include a photoresist material or be on the insulating layer **113** by patterning an insulating layer, e.g., silicon nitride (SiNx), silicon oxide (SiOx), etc.

Before a power source voltage is applied to the first electrodes **112** and the second electrode **123**, the pixels PX display a black gray scale since the second fluid covers the insulating layer **113**. When the power source voltage is applied to the first electrodes **112** and the second electrode **123**, the first fluid is polarized to push the second fluid to a side of the pixels PX, so that the first fluid makes contact with the insulation layer. In this case, the incident light passes through the first fluid disposed in the area not overlapped by the second fluid. The light passing through the first fluid passes through the color filters and is perceived to a viewer. According to an amount of the second fluid pushed out by the first fluid, a contrast ratio may be controlled.

Exemplary embodiments of the arrangement and operation of the first and second fluids will be described in detail with reference to FIGS. **3**A and **3**B.

Although not shown in FIG. **1**, the electro-wetting display apparatus **100** may further include a backlight unit disposed under the first substrate **110** to provide the light to the pixels PX. The backlight unit includes a plurality of light sources, e.g. a light emitting diode, a cold cathode fluorescent lamp, etc.

When the second electrode **123** is the single body without the openings **124**, a portion of the light may not transmit through the second electrode **123** since the transmittance of the second electrode **123** is not 100%. However, when the second electrode **123** includes the openings **124** corresponding to the areas excluding material of the second electrode **123**, the light may transmit through the openings **124**. Thus, the electro-wetting display apparatus **100** may improve the transmittance of the light.

FIGS. **3**A and **3**B are cross-sectional views showing exemplary embodiments of a cross-sectional structure of an electro-wetting display apparatus according to the invention. In detail, FIG. **3**A shows the arrangement of the fluids when no power source voltage is applied to the electrodes, and FIG. **3**B shows the arrangement of the fluids when the power source voltage is applied to the electrodes.

Referring to FIG. **3**A, the fluid **130** includes the first fluid **131** and the second fluid **132**. The first fluid **131** is the polar fluid and has the hydrophilicity property. In one exemplary embodiment, for instance, the first fluid **131** may include water or an electrolyte solution to transmit the light incident thereto.

The second fluid **132** is disposed directly on the insulating layer **113**, and between the first fluid **131** and the insulating layer **113**. The first fluid **131** and the second fluid **132** have different specific gravities from each other, so the first fluid **131** and the second fluid **132** are not mixed with each other. The first fluid **131** is disposed on the second fluid **132** to make contact with the second fluid **132** and forms a boundary therebetween.

The electro-wetting display apparatus **100** controls movements of the first fluid **131** and the second fluid **132** using the voltages applied to the first electrodes **112** and the second electrode **123** to display a desired gray scale.

In one exemplary embodiment, as an example, the second fluid **132** includes a dye that represents one of the red, green and blue colors or a material that represents the red, green and blue colors. In this case, the electro-wetting display apparatus **100** does not need to include the color filters **122**.

Each of the pixels PX includes an area "A" corresponding to an area between the pixel wall **114** and the first electrode **112**. The areas "A" exclude the first electrodes **112**. As described above, the surface of the insulating layer **113** adjacent to the fluid **130** has the hydrophobicity property.

In the case that the power source voltage is not applied to the first electrodes **112** and the second electrode **123**, an entire of the insulating layer **113** is covered and overlapped by the second fluid **132**. Accordingly, the electro-wetting display apparatus **100** displays the black gray scale since light is blocked by the second fluid **132**.

Referring to FIG. **3**B, when the power source voltage is applied to the first electrodes **112** and the second electrode **123**, the first fluid **131** makes contact with the insulating layer **113**. In detail, when a negative (−) voltage is applied to the first electrodes **112** and a positive (+) voltage is applied to the second electrode **123**, the first fluid **131** disposed on the second fluid **132** is polarized. Thus, the first fluid **131** makes contact with the insulating layer **113** and pushes the second fluid **132** to the area "A".

In this case, the light incident to the pixel PX passes through the first fluid **131** except the area "A" in which the second fluid **132** is gathered. The light passing through the first fluid **131** passes through the color filters **122** of the second substrate **120** to be perceived to the viewer. According to the amount of the second fluid **132** displaced by the first fluid **131**, the contrast ratio may be controlled. The amount of the second fluid **132** displaced by the first fluid **131** may be adjusted by the level of the voltages applied to the first electrodes **112** and the second electrode **123**.

The pixel wall **114** disposed on the insulating layer **113** has a height taken from the first base substrate **111** greater than that of the second fluid **132** gathered at the area "A" disposed at the side of each pixel PX. In FIGS. **3**A and **3**B, the pixel wall **114** does not make contact with the second electrode **123**, but the pixel wall **114** may contact with the second electrode **123** according to alternative exemplary embodiments.

Consequently, although the voltage is applied to a portion of the pixel PX through the second electrode **123**, the first fluid **131** makes contact with the insulating layer **113** and the second fluid **132** is pushed to the area "A" by the first fluid **131**.

FIG. **4** is a graph showing experimental results of transmittance of a variety of electro-wetting display apparatus structures. FIG. **4** shows transmittances in percent (%) measured when the second electrode is substantially excluded, when the second electrode is the single body without the openings, and the second electrode **123** is patterned to include the openings **124**. The second electrode patterned to include the openings has the area that is reduced by about 87.89% when compared with the area of the second electrode as the single body without the openings.

Referring to FIG. **4**, the light transmittance is about 74.8 percent (e.g., bare glass) when the electro-wetting display apparatus does not include the second electrode. When the electro-wetting display apparatus includes the second electrode as the single body without the openings (e.g., ITO), the light transmittance is about 68.8 percent. When an exemplary embodiment of the electro-wetting display apparatus **100** includes the second electrode **123** that is patterned to include the openings **124** as shown in FIG. **2**, the light transmittance is about 74.1 percent.

According to the experimental results, the light transmittance may be greater when the second electrode **123** includes the openings **124** respectively corresponding to the pixels PX than the light transmittance when the second electrode **123** is the single body without the openings.

FIG. **5** is a plan view showing another exemplary embodiment of a second electrode of an electro-wetting display apparatus according to the invention. The second electrode shown in FIG. **5** has the substantially same structure as the second electrode shown in FIG. **2** except for the shape of the openings. For the convenience of explanation, the pixel wall has been shown as a dotted line and a darker gray color and the second electrode has been shown as a solid line and an area shaded with an oblique line in FIG. **5**.

Referring to FIG. **5**, the second electrode **123** includes a plurality of openings **124** respectively corresponding to the pixels PX. Each of the openings **124** of the second electrode **123** has a planar shape bent at a right angle, such as an "L" shape. That is, the second electrode **123** in the pixels PX includes an expanded portion which extends to a center portion of the openings **124** from a side of the openings **124**, and the expanded area of the second electrode **123** may have a quadrilateral or right-angle planar shape.

Consequently, since the exemplary embodiment of the second electrode **123** includes the openings **124**, the electro-wetting display apparatus **100** may improve the light transmittance different from that measured when the second electrode is the single body without the openings.

FIG. **6** is a plan view showing another exemplary embodiment of a second electrode of an electro-wetting display apparatus according to the invention. For the convenience of explanation, the pixel wall has been shown as a dotted line and a darker gray color, and the second electrode has been shown as a solid line and an area shaded with an oblique line in FIG. **6**.

Referring to FIG. **6**, the second electrode **123** includes a plurality of openings **124** respectively corresponding to the pixels PX. A width W1 of the pixel wall **114** disposed between two pixels PX adjacent to each other is larger than a width W2 between two openings **124** adjacent to each other.

As described with reference to FIG. **2**, the area of the second electrode **123** including the openings **124** is reduced by about 87.89% when compared with the area of the second electrode **123** as the single body without the openings **124**. However, the width W1 of the pixel wall **114** is larger than the width W2 of the second electrode **123** as shown in FIG. **6**. Thus, the area of the second electrode **123** including the openings **124** may be reduced by more than 87.89% when compared with the area of the second electrode as the single body without the openings **124**.

Consequently, since the exemplary embodiment of the second electrode **123** includes the openings **124**, the electro-wetting display apparatus **100** may improve the light transmittance different from that measured when the second electrode is the single body without the openings.

FIGS. **7**A to **7**C are plan views showing other exemplary embodiments of plan structures of an electro-wetting display apparatus according to the invention. For the convenience of explanation, a pixel wall has been shown as a dotted line and a darker gray color, and a second electrode has been shown as a solid line and shaded with an oblique line in FIGS. **7**A to **7**C.

The electro-wetting display apparatus **200** of FIGS. **7**A to **7**C has the same configurations as those of the electro-wetting display apparatus **100** of FIGS. **1**, **2**, **5** and **6** except the structure of the openings. Accordingly, the structure of the openings will be mainly described in the electro-wetting display apparatus **200**.

Referring to FIGS. **7**A to **7**C, a second electrode **223** of the electro-wetting display apparatus **200** includes a plurality of openings **224**. As described above, the pixels PX are arranged in "n" rows by "m" columns. The openings **224** respectively correspond to pixel units. Each of the pixel units collectively includes two or more, but equal to or less than "m" pixels PX.

In one exemplary embodiment, for instance, as shown in FIG. **7**A, the second electrode **223** may include the openings **224** respectively corresponding to the pixel units, each of which is configured to include two pixels PX arranged in each row. In addition, as shown in FIG. **7**B, the second electrode **223** may include the openings **224** respectively corresponding to the pixel units, each of which is configured to include three pixels PX arranged in each row. As shown in FIG. **7**C, the second electrode **223** may include the openings **224** respectively corresponding to the pixel units, each of which is configured to include "m" pixels PX arranged in each row. The structure shown in FIG. **7**C may be defined as a long, narrow band or stripe structure. Although not shown in FIGS. **7**A to **7**C, the second electrode **223** may include the openings **224** respectively corresponding to the pixel units, each of which is configured to include four or more pixels PX arranged in each row.

However, the configuration of the openings **224** should not be limited thereto or thereby. In an alternative exemplary embodiment, for example, although not shown in FIGS. **7**A to **7**C, the second electrode **223** may include both the openings **224** respectively corresponding to the pixel units, each of which is configured to include two pixels PX arranged in each row, and the openings **224** respectively corresponding to the pixel units, each of which is configured to include three pixels PX arranged in each row. In addition, the second electrode

223 may include both the openings 224 respectively corresponding to the pixel units, each of which is configured to include two pixels PX arranged in each row, and the openings 224 respectively corresponding to the pixel units, each of which is configured to include (m−2) pixels PX arranged in each row. In this case, "m" is a constant number larger than four and each row of the second electrode 223 includes two openings 224.

Although not shown in FIGS. 7A to 7C, the openings 224 of the second electrode 223 may correspond to pixel units, each of which is configured to include two or more, but equal to or less than "m" pixels arranged in each row.

The openings 224 have the rectangular planar shape, but the openings 224 should not be limited to the rectangular shape.

As shown in FIGS. 7A to 7C, a width W1 of the pixel wall 214 disposed between two pixels PX adjacent to each other is smaller than a width W2 between two openings 224 adjacent to each other. Although not shown in FIGS. 7A to 7C, the width W1 of the pixel wall 214 disposed between two pixels PX adjacent to each other may be larger than the width W2 between two openings 224 adjacent to each other. In addition, the width W1 of the pixel wall 214 disposed between two pixels PX adjacent to each other may be the same as the width W2 between two openings 224 adjacent to each other.

As described with reference to FIG. 2, the area of the second electrode 123 including the openings 124 respectively corresponding to the pixel PX may be reduced by about 87.89% when compared with the area of the second electrode as the single body without the openings. However, the openings 224 of the second electrode 223 shown in FIGS. 7A to 7C respectively correspond to pixel units, each of which is configured to include two or more but equal to or less than "m" pixels arranged in each row. Thus, the area of the second electrode 223 including the openings 224 shown in FIGS. 7A to 7C may be reduced by more than 87.89% when compared with the area of the second electrode as the single body without the openings.

Consequently, since the exemplary embodiments of the second electrode 223 include the openings 224, the electro-wetting display apparatus 200 may improve the light transmittance different from that measured when the second electrode is the single body without the openings.

FIGS. 8A to 8C are plan views showing still other exemplary embodiments of a plan structure of an electro-wetting display apparatus according to the invention. For the convenience of explanation, a pixel wall has been shown as a dotted line and a darker gray color, and a second electrode has been shown as a solid line and shaded with an oblique line in FIGS. 8A to 8C.

The electro-wetting display apparatus 300 of FIGS. 8A to 8C has the same configurations as those of the electro-wetting display apparatus 100 of FIGS. 1, 2, 5 and 6 except the structure of the openings. Accordingly, the structure of the openings will be mainly described in the electro-wetting display apparatus 300.

Referring to FIGS. 8A to 8C, a second electrode 323 of the electro-wetting display apparatus 300 includes a plurality of openings 324. As described above, the pixels PX are arranged in "n" rows by "m" columns. The openings 224 respectively correspond to pixel units. Each of the pixel units collectively includes pixels PX arranged in two rows by two or more columns, but equal to or less than "m" columns

In one exemplary embodiment, for instance, as shown in FIG. 8A, the second electrode 323 may include the openings 324 respectively corresponding to the pixel units, each of which is configured to include four pixels PX arranged in two rows by two columns. In addition, as shown in FIG. 8B, the second electrode 323 may include the openings 324 respectively corresponding to the pixel units, each of which is configured to include six pixels PX arranged in two rows by three columns. As shown in FIG. 8C, the second electrode 323 may include the openings 324 respectively corresponding to the pixel units, each of which is configured to include the pixels PX arranged in two rows by "m" columns. The structure shown in FIG. 8C may be defined as the stripe structure. Although not shown in FIGS. 8A to 8C, the second electrode 323 may include the openings 324 respectively corresponding to the pixel units, each of which is configured to include the pixels PX arranged in two rows by four or more columns.

However, the configuration of the openings 324 should not be limited thereto or thereby. In one exemplary embodiment, for example, although not shown in FIGS. 8A to 8C, the second electrode 323 may include both the openings 324 respectively corresponding to the pixel units, each of which is configured to include four pixels PX arranged in two rows by two columns, and the openings 324 respectively corresponding to the pixel units, each of which is configured to include six pixels PX arranged in two rows by three columns. In addition, the second electrode 323 may include both the openings 324 respectively corresponding to the pixel units, each of which is configured to include four pixels PX arranged in two rows by two columns, and the openings 324 respectively corresponding to the pixel units, each of which is configured to include the pixels PX arranged in two rows by (m−2) columns. In this case, "m" is a constant number larger than four and each row of the second electrode 323 includes two openings 324.

Although not shown in FIGS. 8A to 8C, the openings 324 of the second electrode 323 may correspond to pixel units, each of which is configured to include the pixels arranged in two columns, by two or more but equal to or less than "n" rows.

The openings 324 have the rectangular planar shape, but the openings 324 should not be limited to the rectangular shape.

As shown in FIGS. 8A to 8C, a width W1 of the pixel wall 314 disposed between two pixels PX adjacent to each other is smaller than a width W2 between two openings 324 adjacent to each other. Although not shown in FIGS. 8A to 8C, the width W1 of the pixel wall 314 disposed between two pixels PX adjacent to each other may be larger than the width W2 between two openings 324 adjacent to each other. In addition, the width W1 of the pixel wall 314 disposed between two pixels PX adjacent to each other may be the same as the width W2 between two openings 324 adjacent to each other.

As described with reference to FIG. 2, the area of the second electrode 123 including the openings 124 respectively corresponding to the pixel PX may be reduced by about 87.89% when compared with the area of the second electrode as the single body without the openings. However, the openings 324 of the second electrode 323 shown in FIGS. 8A to 8C respectively correspond to pixel units, each of which is configured to include pairs of pixels arranged in two rows by "k" columns. Thus, the area of the second electrode 323 including the openings 324 shown in FIGS. 8A to 8C may be reduced by more than 87.89% when compared with the area of the second electrode as the single body without the openings.

Consequently, since the exemplary embodiment of the second electrode 323 includes the openings 324, the electro-wetting display apparatus 300 may improve the light transmittance different from that measured when the second electrode is the single body without the openings.

FIG. **9** is a cross-sectional view showing another exemplary embodiment of a cross-sectional structure of an electro-wetting display apparatus according to the invention. The electro-wetting display apparatus **400** of FIG. **9** has the substantially same structure and function as that of the electro-wetting display apparatuses **100**, **200**, and **300** of previous exemplary embodiments except that the electro-wetting display apparatus **400** includes a reflective layer.

Referring to FIG. **9**, the electro-wetting display apparatus **400** includes a first substrate **410**, a second substrate **420** facing the first substrate **410**, and a fluid **430** disposed between the first substrate **410** and the second substrate **420**.

The first substrate **410** includes a first base substrate **411**, a reflective layer **412** disposed on the first base substrate **411**, a plurality of first electrodes **413** disposed on the reflective layer **412**, an insulating layer **414** disposed on the reflective layer **412** to cover the first electrodes **413**, and a pixel wall **415** disposed on the insulating layer **414** to define the pixels PX. The first electrodes **413** respectively correspond to the pixels PX.

The second substrate **420** includes a second base substrate **421** facing the first base substrate **411**, color filters **422** disposed on the second base substrate **421**, and a second electrode **423** disposed on the color filters **422** and including a plurality of openings **424**. The reflective layer **412** reflects the light incident thereto. That is, the light passing through the second substrate **420** is reflected by the reflective layer **412** toward the second substrate **420**.

The configuration and operation of the electro-wetting display apparatus **400** are the same as those of the electro-wetting display apparatuses **100**, **200** and **300** according to the previous exemplary embodiments.

Consequently, since the second electrode **423** includes the openings **424**, the exemplary embodiment of electro-wetting display apparatus **400** may improve the light transmittance different from that measured when the second electrode is the single body without the openings.

Although exemplary embodiments of the invention have been described, it is understood that the invention should not be limited to these exemplary embodiments but various changes and modifications can be made by one ordinary skilled in the art within the spirit and scope of the invention as hereinafter claimed.

What is claimed is:

1. An electro-wetting display apparatus comprising:
- a first substrate;
- a plurality of first electrodes disposed on the first substrate;
- a hydrophobic surface disposed on the plurality of first electrodes;
- pixel walls disposed on the hydrophobic surface, wherein the pixel walls intersect to partition a plurality of pixels, wherein the plurality of pixels respectively corresponds to the plurality of first electrodes such that each pixel includes a corresponding first electrode, and wherein each corresponding first electrode is spaced from at least one pixel wall to define a region within the pixel that includes the corresponding first electrode;
- a second substrate that faces the first substrate;
- a second electrode disposed on the second substrate; and
- a first fluid disposed on a second fluid, wherein the second fluid is disposed on the hydrophobic surface and is substantially immiscible with the first fluid, and wherein the first fluid and the second fluid are disposed in each of the pixels of the plurality of pixels between the first substrate and the second substrate,
- wherein displacement of the second fluid on the hydrophobic surface to the regions in the plurality of pixels, such that the first fluid replaces the second fluid on a portion of the hydrophobic surface, is controlled by voltages that are respectively applied to the plurality of first electrodes and the second electrode.

2. The electro-wetting display apparatus of claim **1**, further comprising:
- an insulating layer disposed on the plurality of first electrodes,
- wherein the hydrophobic surface is disposed on the insulating layer.

3. The electro-wetting display apparatus of claim **1**, further comprising:
- an insulating layer disposed on the plurality of first electrodes,
- wherein the hydrophobic surface comprises a hydrophobic layer disposed on the insulating layer.

4. The electro-wetting display apparatus of claim **1**, wherein the second fluid comprises one of a red, green or blue color.

5. The electro-wetting display apparatus of claim **1**, further comprising:
- color filters disposed on the second substrate,
- wherein the second electrode is disposed on the color filters, and
- wherein each color filter comprises a corresponding one of (i) a red color, (ii) a green color or (iii) a blue color.

6. The electro-wetting display apparatus of claim **1**, wherein the plurality of first electrodes comprise a transparent conductive material.

7. The electro-wetting display apparatus of claim **6**, wherein the plurality of first electrodes comprise one of (i) indium tin oxide, (ii) conductive polymer or (iii) carbon nanotube.

8. The electro-wetting display apparatus of claim **1**, wherein the second electrode comprises a transparent conductive material.

9. The electro-wetting display apparatus of claim **8**, wherein the second electrode comprises indium tin oxide.

10. The electro-wetting display apparatus of claim **1**, wherein the second electrode is substantially aligned with portions of the pixel walls, wherein the second electrode includes a plurality of openings, and wherein each opening of the plurality of openings has a shape and size that substantially corresponds to a shape and size of one or more pixels of the plurality of pixels.

11. The electro-wetting display apparatus of claim **10**, wherein the shape and size of each opening substantially corresponds to the shape and size of a single pixel.

12. The electro-wetting display apparatus of claim **11**, wherein:
- each of the plurality of openings has a rectangular shape, and
- a width of the pixel wall between two adjacent pixels is smaller than a width of the second electrode between two adjacent openings.

13. The electro-wetting display apparatus of claim **11**, wherein
- each of the plurality of openings has a rectangular shape, and
- a width of the pixel wall between two adjacent pixels is larger than a width of the second electrode between two adjacent openings.

14. The electro-wetting display apparatus of claim **11**, wherein
- each of the plurality of openings has a rectangular shape, and

a width of the pixel wall between two adjacent pixels is equal to a width of the second electrode between two adjacent openings.

15. The electro-wetting display apparatus of claim **1**, wherein the first fluid is substantially transparent, and wherein the second fluid is substantially non-transparent.

16. The electro-wetting display apparatus of claim **1**, wherein a height of the pixel walls is greater than a height of the second fluid when the second fluid is displaced to the regions of the pixels.

17. The electro-wetting display apparatus of claim **10**, wherein each opening of the plurality of openings has a shape and a size that substantially corresponds to the shape and size, respectively, of two or more pixels of the plurality of pixels.

18. The electro-wetting display apparatus of claim **10**, wherein each opening of the plurality of openings has a shape and a size that substantially corresponds to the shape and size of three or more pixels of the plurality of pixels.

19. The electro-wetting display apparatus of claim **10**, wherein each opening of the plurality of openings has a shape and a size that substantially corresponds to the shape and size of four pixels of the plurality of pixels arranged in a two by two configuration.

20. The electro-wetting display apparatus of claim **10**, wherein each opening of the plurality of openings has a shape and a size that substantially corresponds to the shape and size of six pixels of the plurality of pixels arranged in a two by three configuration.

21. The electro-wetting display apparatus of claim **1**, further comprising a reflective layer that reflects light incident thereto, wherein the reflective layer is between the first substrate and the hydrophobic surface disposed on the plurality of first electrodes.

22. An electro-wetting display apparatus comprising:

a first substrate;

a plurality of first electrodes disposed on the first substrate;

a hydrophobic surface disposed on the plurality of first electrodes;

pixel walls disposed on the hydrophobic surface, wherein the pixel walls intersect to partition a plurality of pixels, wherein the plurality of pixels respectively corresponds to the plurality of first electrodes such that each pixel includes a corresponding first electrode, and wherein each corresponding first electrode is spaced from at least one pixel wall to define a region within the pixel that includes the corresponding first electrode;

a second substrate that faces the first substrate;

a second electrode on the second substrate, wherein the second electrode substantially aligns with the pixel wall and defines a plurality of openings, and wherein a corresponding portion of the second electrode extends into a corresponding opening such that each opening of the plurality of openings has a shape that is bent at a right angle in a substantially L shape over a corresponding pixel of the plurality of pixels;

a first fluid disposed on a second fluid, wherein the second fluid is disposed on the hydrophobic surface and is substantially immiscible with the first fluid, and wherein the first fluid and the second fluid are disposed in each of the pixels of the plurality of pixels between the first substrate and the second substrate,

wherein displacement of the second fluid on the hydrophobic surface to the regions in the plurality of pixels, such that the first fluid replaces the second fluid on a portion of the hydrophobic surface, is controlled by voltages that are respectively applied to the plurality of first electrodes and the second electrode.

23. The electro-wetting display apparatus of claim **22**, further comprising:

an insulating layer disposed on the plurality of first electrodes,

wherein the hydrophobic surface is disposed on the insulating layer.

24. The electro-wetting display apparatus of claim **22**, further comprising:

an insulating layer disposed on the plurality of first electrodes,

wherein the hydrophobic surface comprises a hydrophobic layer disposed on the insulating layer.

* * * * *